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SACRAMENTO-SAN JOAQUIN DELTAPART II
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✓ DISTRIBUTION OF ADULT AND SUBADULT
STRIPED BASS, *ROCCUS SAXATILIS*, IN THE
SACRAMENTO-SAN JOAQUIN DELTA

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The number of adult striped bass in the Sacramento-San Joaquin Delta varies widely throughout the year for, being anadromous fish, they spend a large part of their lives in San Francisco, San Pablo, and Suisun bays or in the Pacific Ocean.

This report describes the distribution of adult (1960 and earlier year-classes) and subadult (1961 year-class) striped bass in the Delta for the period of September 1963 through August 1964. It is based on an analysis of gill net catches made once a month at 16 stations. Roughly 6,000 bass were caught.

Relatively few striped bass were found in the Delta during the fall and winter. Large numbers of mature adults entered the Delta in the spring, a large run of males preceding the females. Bass in the northern Delta migrated rapidly up the Sacramento River, while those in the central Delta concentrated in the lower San Joaquin River during the spawning period. High concentrations of total dissolved solids at and upstream from Stockton appear to have blocked the spawning migration up the San Joaquin River.

METHODS

The sampling techniques and the location of sampling stations are described in the introductory paper of this bulletin. The interpretation of gill net catches and determination of sexual maturity are also described there.

The year-classes of striped bass were identified by length-frequency analysis of the gill net catch (Figure 1). Fish of the 1960 or earlier year-classes are called *adults* in this paper. Gonad examination revealed that most were capable of spawning in 1964. Only a portion of the 1961 year-class was capable of spawning in 1964. Members of this group are referred to as *subadults*.

Gonads were examined to determine how sex and maturity were related to distribution. When possible at least 10 adults and 10 subadults were examined at each station each month. Sample sizes were too small to estimate sex ratios reliably for each station each month. The ratios used in the analysis were obtained by combining the samples of fish sexed at similar and nearby stations and calculating the sex ratio for the group. The groups included stations in (i) the Sacramento River, (ii) the Mokelumne River, (iii) Hog and Sycamore sloughs, (iv) Franks Tract and Big Break, (v) San Joaquin River below the City of Stockton, (vi) the San Joaquin River above Stockton (Mossdale), Old River, Fabian and Bell Canal, and Indian Slough (Figure 2A).

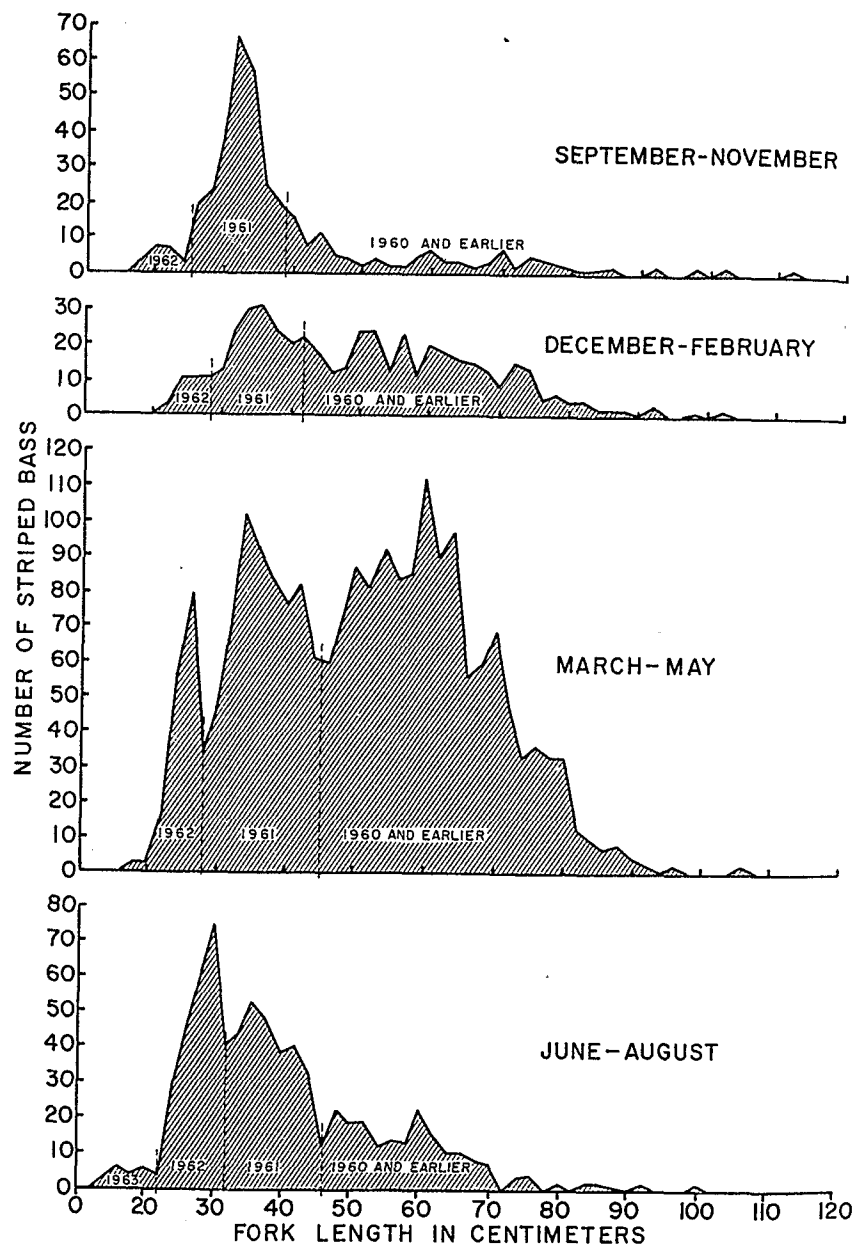


FIGURE 1. Length-frequency distribution of striped bass caught in gill nets. Year-class divisions are indicated by dotted lines.

DISTRIBUTION OF ADULTS IN FALL AND WINTER

Catches of adult striped bass were low at nearly all stations from September through February (Figure 2B, C, D). The only exception

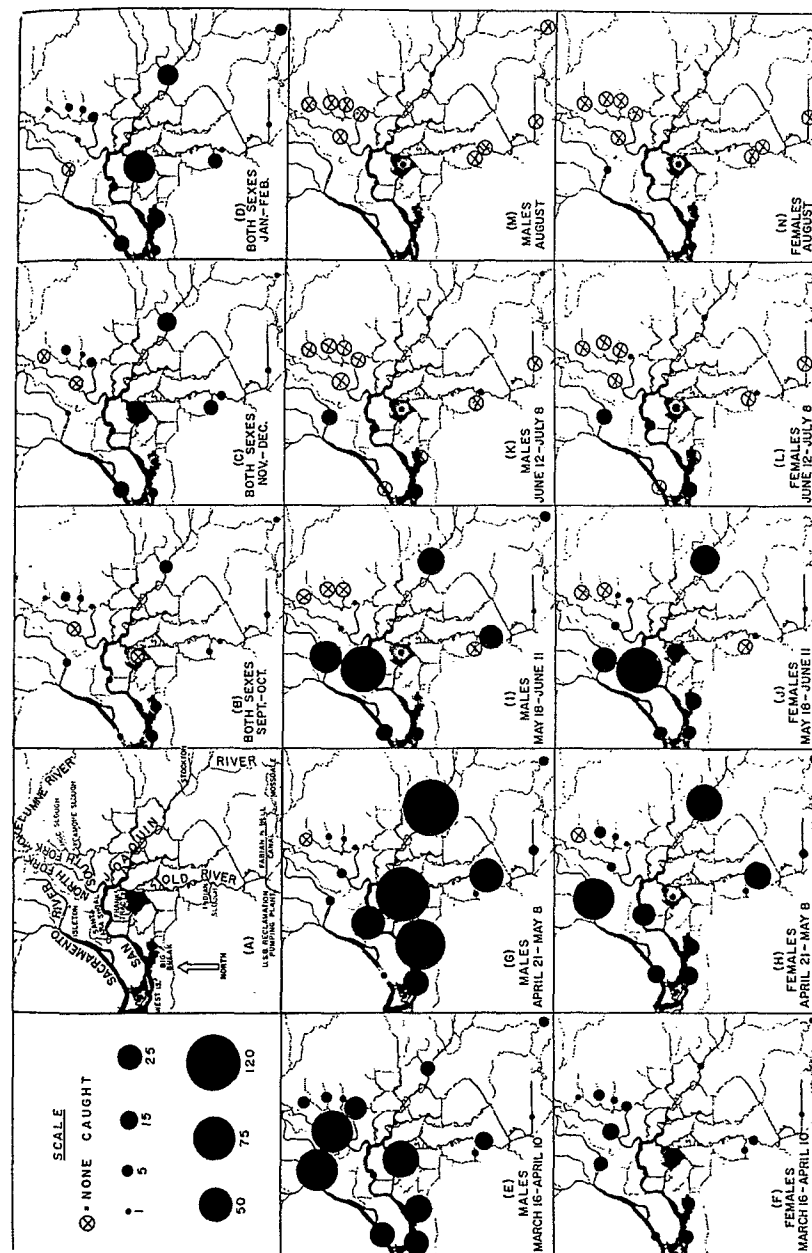


FIGURE 2. Distribution of adult striped bass in the Delta. The area of each circle is proportional to the catch per gill net unit. (A) shows locations mentioned in the text. Circles in (B) through (D) represent averages of two monthly samples at each station. Circles in (E) through (N) represent one sample at each station during each period.

Fig. 1

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was Franks Tract where catches increased from zero in September and October to 24.5 fish per gill net unit on January 22 and 57.5 per unit on February 19. The generally low catches probably indicate that there were few adults in the Delta during this period.

The higher catches at Franks Tract in January and February may be the result of a population increase there, although why this would happen is unknown. Temperature was essentially the same there as in the surrounding waterways. A food habits investigation in the Delta concurrent with the present study indicates that the percentage of adult bass stomachs containing food was higher in fall and winter than during spring (see Stevens, p. 76). But other areas of the Delta had higher concentrations of forage fish than Franks Tract during this time (see Sasaki, p. 48; see Turner, p. 160). Therefore, it is doubtful that food alone attracted adult bass to Franks Tract. Perhaps the relative stillness of the water, with only tidal currents, attracted them.

DISTRIBUTION OF ADULTS IN SPRING AND SUMMER

Catches during late March and early April suggest a migration primarily of males up the Sacramento River and into the western San Joaquin Delta (Figure 2E, F).

Catches during late April and early May indicate that most males in the Sacramento River had migrated upstream (Figure 2G). There were many males in the San Joaquin River below Stockton, in the central Delta, and in part of the southern Delta.

Females migrated into the Sacramento River during late April and early May (Figure 2H). Females were also present in the San Joaquin River below Stockton and in part of the southern Delta.

During late May and early June, the heaviest concentration of males in the San Joaquin Delta was in the Santa Clara Shoal area of the San Joaquin River (Figure 2I). Catches declined in most other areas of the San Joaquin Delta. Virtually all males were ripe.

Calhoun (1946) reported high numbers of ripe male bass caught by anglers in Franks Tract in mid April 1946. He found that in the latter half of April, the catch in Franks Tract dropped sharply, while catches of ripe males in the main San Joaquin increased and remained high through most of May. This pattern of movement is similar to that indicated by the present study.

Females in the Sacramento River migrated upstream during late May and early June (Figure 2J). Those in the San Joaquin River concentrated mainly in the Santa Clara Shoal area. Farley (see p. 34) found evidence of heavy spawning in the lower portion of the San Joaquin River, including Santa Clara Shoal, in mid May 1964. He found little evidence of spawning in other areas of the San Joaquin Delta.

Although adult males and females entered the San Joaquin River in large numbers during the spring, few migrated upstream beyond Stockton or into Fabian and Bell Canal.

Catches of both sexes were low from early June to early July (Figure 2K, L). Eighty percent of the females caught were spent. Most bass had spawned and left the Delta by this time. By August, very few remained (Figure 2M, N).

DISTRIBUTION OF SUBADULTS

Few subadults were caught, compared to adults. This may be partly explained by the fact that several year-classes were included in the adult classification while only the 1961 year-class made up the subadults.

Few subadults were caught from September through February (Figure 3A, B, C). From mid March to early June, the distribution pattern of subadult males resembled that of adult males; i.e., those in the Sacramento River migrated upstream, while those in the San Joaquin remained in the central and western Delta (Figure 3D, F, H). Approximately 65 percent of the subadult males caught from mid May to early June were ripe; they probably spawned with the adults. During the summer they migrated into the bay (Figure 3J, L).

The few subadult females caught during spring and summer (Figure 3E, G, I, K, M) were immature. Few female striped bass mature before their fourth year (Scofield, 1931), and few migrate from the bay into the Delta before this time (Chadwick, 1967).

GEOGRAPHICAL POPULATION DIFFERENCES

The Delta is a maze of channels that vary in width from a few hundred feet to a mile. While gill net catches are comparable expressions of *concentration*, they are not comparable expressions of the *relative numbers* or *abundance* of fish in different parts of the Delta. The entire fish population could be contained in the wide channels of the western Delta with a concentration (and therefore a net catch) only a fraction of that which would result from containing the same population in the smaller channels of the eastern Delta. To achieve an index of relative abundance in various parts of the Delta, stations were grouped on the basis of river system and flow and delineated into zones. Sasaki, (see p. 52) illustrates these geographical areas and the stations in them. The mean seasonal catch of bass in each zone (*index of concentration*) was multiplied by the percent of the Delta's surface area represented by each zone. The resulting figures are *population indices* for each zone, which I converted to percent of total bass in the Delta (Tables 1 and 2). The population indices of the zones were totaled to obtain population indices for the entire Delta each season (*quarterly population indices*).

The quarterly population indices suggest that the number of adult bass in the Delta increased greatly from fall to spring and decreased from spring to summer (Table 1). While these changes in the index are probably due primarily to migration, the magnitude of change was undoubtedly influenced by the effects of various factors on the gill net catches. For instance, from fall to winter the actual population of adult bass in the Delta may have increased by much more than is indicated. Low temperatures probably caused a decrease in fish activity, resulting in disproportionately low catches and an underestimate of the increase. The increase in the index from winter to spring is probably disproportionately large due to increased fish activity caused by rising temperature and approaching sexual maturity.

During the fall, winter, and spring, most adult bass in the Delta were located in the flooded islands, the Sacramento River, and the lower and

FIGURE 3. Distribution of subadult striped bass in the Delta. The area of each circle is proportional to the catch per gill net unit. Circles in (A) through (C) represent averages of two monthly samples at each station. Circles in (D) through (M) represent one sample at each station during each period.

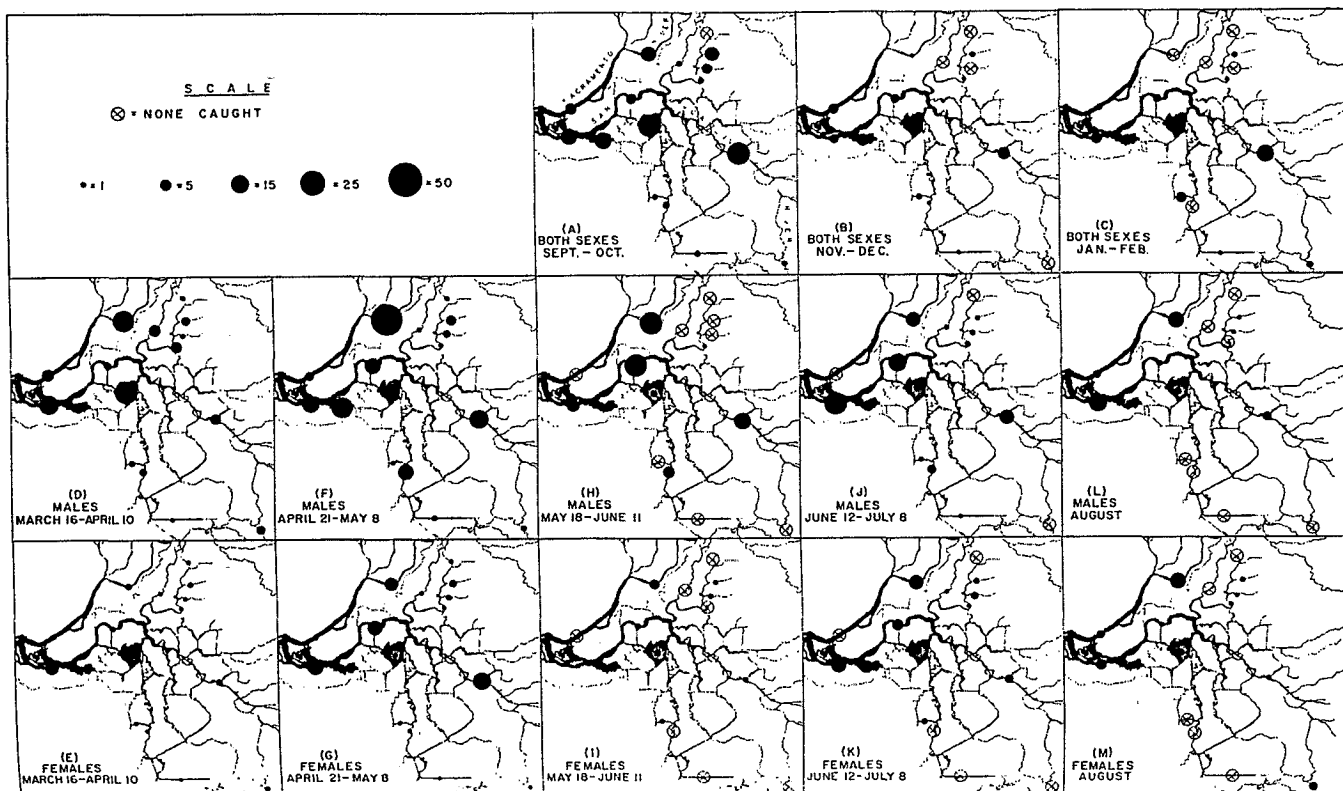


Table 1

TABLE 1
Relative Abundance of Adult Striped Bass in Zones of the Delta

| Zones | Percent of Delta Area | Fall | | | Winter | | | Spring | | | Summer | | |
|-----------------------------------|-----------------------|------------------------|------------|-------------------------|------------------------|------------|-------------------------|------------------------|------------|-------------------------|------------------------|------------|-------------------------|
| | | Index of concentration | Pop. index | Percent of pop. in zone | Index of concentration | Pop. index | Percent of pop. in zone | Index of concentration | Pop. index | Percent of pop. in zone | Index of concentration | Pop. index | Percent of pop. in zone |
| Lower San Joaquin River..... | 24.6 | 3.4 | 83.4 | 16.3 | 6.2 | 153.3 | 10.6 | 102.2 | 2,515.9 | 32.0 | 9.4 | 231.3 | 21.5 |
| Middle San Joaquin River..... | 12.4 | 9.3 | 115.3 | 22.5 | 15.5 | 192.2 | 13.2 | 82.9 | 1,027.9 | 13.2 | 2.0 | 24.8 | 2.3 |
| Upper San Joaquin River..... | 2.1 | 1.3 | 2.7 | 0.5 | 3.8 | 8.0 | 0.5 | 5.7 | 12.0 | 0.2 | 1.0 | 2.1 | 0.2 |
| Sacramento River..... | 15.3 | 4.5 | 68.9 | 13.5 | 12.2 | 186.7 | 12.8 | 72.7 | 1,112.3 | 14.3 | 36.0 | 550.8 | 51.2 |
| Mokelumne River..... | 5.4 | 2.0 | 10.8 | 2.1 | 4.8 | 25.9 | 1.8 | 41.2 | 222.5 | 2.9 | 2.1 | 11.3 | 1.1 |
| South Delta..... | 15.7 | 2.2 | 34.5 | 6.7 | 3.0 | 47.1 | 3.2 | 43.1 | 676.7 | 8.7 | 1.3 | 20.4 | 1.9 |
| Flooded Islands..... | 17.6 | 7.8 | 137.3 | 26.8 | 43.2 | 760.3 | 52.3 | 122.7 | 2,159.5 | 27.7 | 13.2 | 232.3 | 21.6 |
| Dead-end Sloughs..... | 6.9 | 8.5 | 58.7 | 11.5 | 11.7 | 80.7 | 5.5 | 11.1 | 76.6 | 1.0 | 0.3 | 2.1 | 0.2 |
| Quarterly population indices..... | | | 511.6 | | | 1,454.2 | | | 7,803.4 | | | 1,075.1 | |

TABLE 2
Relative Abundance of Subadult Striped Bass in Zones of the Delta

| Zones | Percent of pop. in zone | Summer | | | Spring | | | Winter | | | Fall | | | Percent of Delta Area |
|-----------------------------------|-------------------------|------------|------------------------|-------------------------|------------|------------------------|-------------------------|------------|------------------------|-------------------------|------------|------------------------|-------------------------|-----------------------|
| | | Pop. index | Index of concentration | Percent of pop. in zone | Pop. index | Index of concentration | Percent of pop. in zone | Pop. index | Index of concentration | Percent of pop. in zone | Pop. index | Index of concentration | Percent of pop. in zone | |
| Lower San Joaquin River..... | 39.1 | 530.9 | 21.5 | 36.3 | 751.6 | 30.6 | 25.6 | 168.2 | 6.8 | 16.1 | 170.7 | 6.9 | 16.1 | 24.6 |
| Middle San Joaquin River..... | 8.7 | 117.8 | 9.5 | 9.7 | 200.9 | 16.2 | 23.5 | 155.0 | 12.5 | 19.2 | 204.6 | 16.5 | 19.2 | 12.4 |
| Upper San Joaquin River..... | 0.2 | 2.7 | 1.3 | 0.2 | 4.8 | 2.3 | 0.4 | 2.7 | 1.3 | 0.1 | 1.5 | 0.7 | 0.1 | 2.1 |
| Sacramento River..... | 27.4 | 371.8 | 24.3 | 21.5 | 445.2 | 20.1 | 7.4 | 49.0 | 3.2 | 16.8 | 179.0 | 11.7 | 16.8 | 15.3 |
| Mokelumne River..... | 0.5 | 7.0 | 1.3 | 1.6 | 34.0 | 6.3 | 0.4 | 2.7 | 0.5 | 4.3 | 12.4 | 2.3 | 4.3 | 5.4 |
| South Delta..... | 1.5 | 20.4 | 1.3 | 6.8 | 141.6 | 8.0 | 0.7 | 4.7 | 0.3 | 13.8 | 44.0 | 2.8 | 13.8 | 15.7 |
| Flooded Islands..... | 19.8 | 269.3 | 15.3 | 20.9 | 432.9 | 24.6 | 36.7 | 242.9 | 13.8 | 35.1 | 373.1 | 21.2 | 35.1 | 17.6 |
| Dead-end Sloughs..... | 2.8 | 37.8 | 6.2 | 3.0 | 62.1 | 9.0 | 5.3 | 34.5 | 5.0 | 7.3 | 78.0 | 11.3 | 7.3 | 6.9 |
| Quarterly population indices..... | | 1,357.7 | | | 2,073.1 | | | 659.7 | | | 1,063.3 | | | |

middle San Joaquin River. During the summer approximately half the Delta population was in the Sacramento River. Quarterly population indices for subadults suggest an overall decrease in numbers in the Delta from fall to winter, followed by a large increase in spring and a decrease in summer (Table 2). Again, these indices undoubtedly reflect, in part, the influences of temperature and spawning activity. The distribution of the subadult population among the various zones of the Delta was similar to that of the adults. The most notable exception was in summer when a substantially higher percentage of subadults was in the lower San Joaquin River and a lower percentage was in the Sacramento River.

WHY DO STRIPED BASS AVOID THE UPPER SAN JOAQUIN RIVER?

Although large numbers of adult and subadult striped bass were caught in all other areas of the Delta in the spring, few were taken in the San Joaquin River above Stockton or in the extreme south Delta. In attempting to explain this, various environmental factors such as food, temperature, flow, and total dissolved solids were considered.

Food

An extensive study of their food habits indicates that few adult bass fed during the spawning migration (see Stevens, p. 76), and because of this, it is doubtful that food availability had much influence on their distribution during this time.

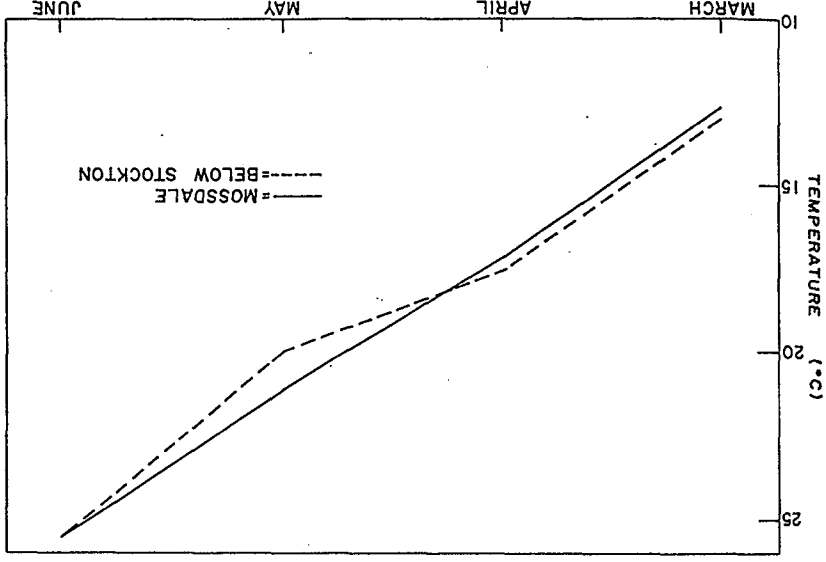


FIGURE 4. Comparison of temperatures in the San Joaquin River just below Stockton and at Mossdale. Temperatures were taken at the time gill nets were retrieved.

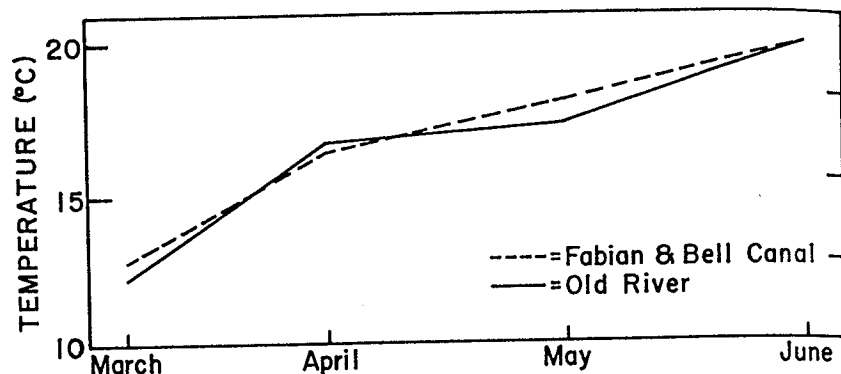


FIGURE 5. Comparison of temperatures in Old River and Fabian and Bell Canal. Temperatures were taken at the time gill nets were retrieved.

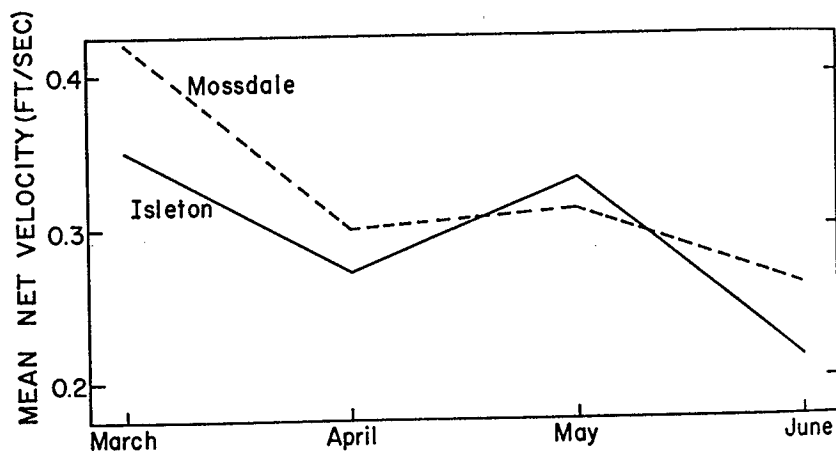


FIGURE 6. Comparison of mean net velocity of flow in the Sacramento River at Isleton and in the San Joaquin River at Mossdale, based on monthly net flows estimated by the California Dept. of Water Resources.

Temperature

Temperature does not appear to have prevented the migration up the San Joaquin River. Just below Stockton, where many bass were caught, temperatures taken during the spawning migration were similar to those taken at Mossdale, where few bass were caught (Figure 4).

In Old River, where large numbers of bass were taken, temperatures differed little from those in the adjacent Fabian and Bell Canal, where very few bass were caught (Figure 5).

Flow

Current velocity in the upper San Joaquin River was not unfavorable for striped bass migration. Mean net velocities¹ at Isleton on the Sac-

¹ Mean net velocity (in feet per second) = $\frac{\text{Net flow (in cubic feet per second)}}{\text{cross sectional area of channel (in sq. ft.)}}$
Turner (1966) discusses this measurement and how it applies to flows in the Delta.

ramento River and at Mossdale on the San Joaquin River were similar during the spring of 1964 (Figure 6). Although this does not mean that actual velocities at these stations were necessarily similar, it does indicate that at both places water moved toward the ocean at about the same rate. If this were the controlling factor, comparable concentrations of striped bass would be expected at both stations during the spawning migration. However, catches indicate that in the spring of 1964, very few went up the San Joaquin, while many went up the Sacramento River.

Dissolved Solids

In the spring of 1964 adult striped bass passed through a 50-mile long section of decreasing salinities in the bays before they reached the fresh water of the Delta. Those that entered the San Joaquin River continued upstream until confronted with increasing total dissolved solids just below Stockton (Figure 7). The bass that migrated into Old River encountered a similar situation at Fabian and Bell Canal in the south Delta. In both instances, migration appeared to cease.

In years of low natural runoff, such as 1964, the San Joaquin River contains relatively high concentrations of sodium chloride during the spring and summer, due to the influence of irrigation water returned to the river from farmlands in the San Joaquin Valley (Calif. Dept. of Water Resources, 1961). A *reverse salinity gradient* is caused by the mixture of San Joaquin and Sacramento River waters as they are drawn to the Delta-Mendota Canal by the U. S. Bureau of Reclamation pumping plant.

During the journey from salt to fresh water, adult striped bass necessarily undergo certain osmoregulatory changes, as do all anadromous fishes during their spawning migrations. Changes in endocrine activity usually accompany or precede changes in osmoregulatory mechanisms, indicating hormonal control. The pituitary, the thyroid, and the gonads are concerned with physiological changes prior to and during migrations. Their secretions may initiate osmoregulatory processes. Lagler, Bardach, and Miller (1962) mention that pituitary and gonadal changes often lead to appetitive behavior, such as the stickleback's, *Gasterosteus*, preference for fresh water when preparing to spawn.

Black (1957) reviewed the literature dealing with osmoregulation in anadromous fishes and cited evidence that anadromous fishes are adjusted to either the freshwater or the saltwater phase of their life cycles and cannot change abruptly from one to the other. For example, the sea lamprey, *Petromyzon marinus*, after having entered fresh water, cannot tolerate even half sea water salinities. It can regulate body fluids until this time but becomes stenohaline upon beginning its anadromous migration.

The physiological effects of the salinity gradient in the San Joaquin River near Stockton and in the south Delta on striped bass are not known. But it seems reasonable to hypothesize that, having been in fresh water for several weeks, their osmoregulatory systems had thoroughly adapted to the freshwater environment. They were probably sensitive to increases in salinity and were able to detect the relatively high salinity of the water from the upper San Joaquin River. When they encountered it, they did not continue upstream.

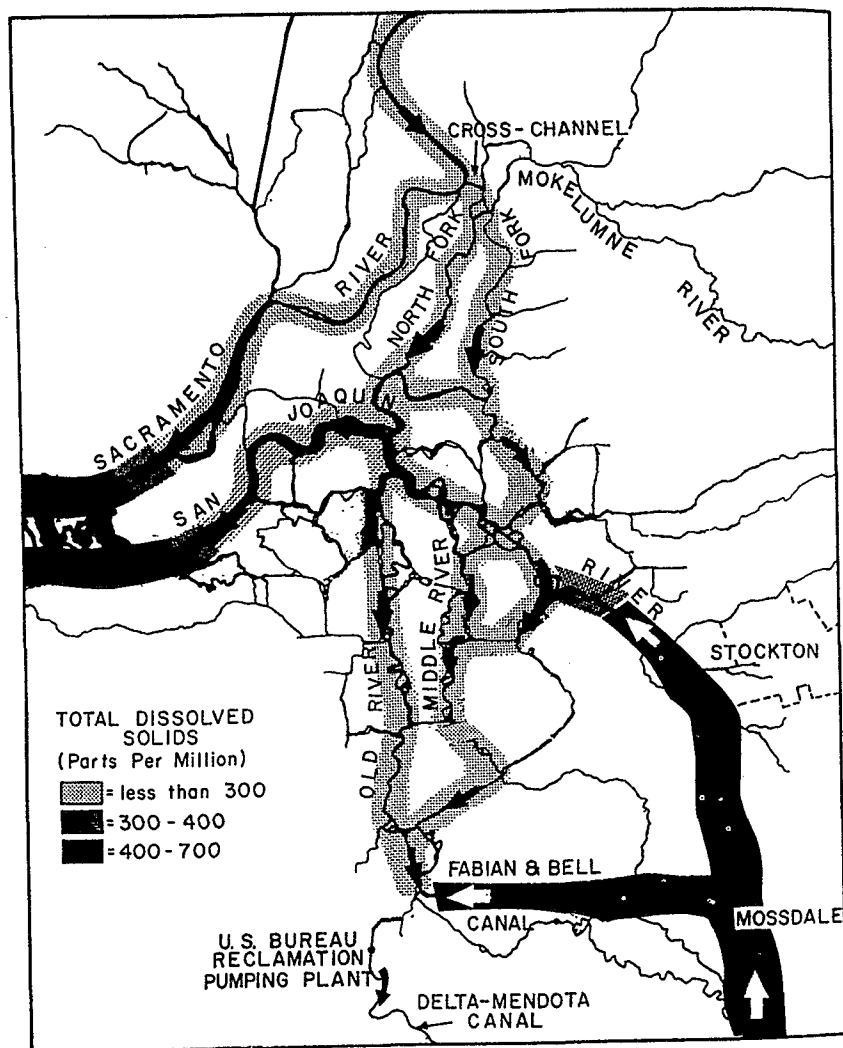


FIGURE 7. Flow pattern and total dissolved solids concentrations in the Delta from March through June 1964. Arrows indicate the direction of net flow, based on monthly flows estimated by the California Dept. of Water Resources. Shaded areas represent ranges of total dissolved solids, based on water samples collected during fish sampling.

Striped bass apparently always spawn in fresh water and, except for a few isolated populations located entirely in fresh water, they migrate from essentially sea water through a salinity gradient to do so (Morgan and Gerlach, 1950; Tresselt, 1952; Rathjen and Miller, 1957). I believe that when the San Joaquin River above Stockton has a high concentration of dissolved solids, striped bass will not migrate upstream to spawn. In years when high flows occur in the San Joaquin River due to natural runoff, the dissolved solids concentration is much lower and striped bass probably migrate upstream. Farley (see p. 37) reviewed the literature on striped bass spawning in the Delta and

found that in years when there was evidence of spawning in the upper San Joaquin River, the dissolved solids concentration was low. According to his data, bass spawned there in the spring of 1963 but not in 1964.

SUMMARY

From September 1963 through August 1964, gill nets were set in the Sacramento-San Joaquin Delta to obtain information on the distribution and abundance of adult and subadult striped bass. Few adult or subadult striped bass were caught in the Delta during fall and winter except in the flooded island, Franks Tract. The major spawning migration of adult striped bass occurred during the spring, with a large run of males preceding the females. The bass that entered the northern Delta migrated upstream in the Sacramento River, while those in the central Delta concentrated in the lower San Joaquin River. Few migrated into the upper San Joaquin River or the extreme south Delta.

Most of the subadult males (3 years old) were mature in the spring and their migration pattern resembled that of adult males. Female subadults were not mature at that time and very few migrated into the Delta.

Relatively high concentrations of total dissolved solids apparently blocked the spawning migration of striped bass into the upper San Joaquin River.

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